Silicon Waveguide Cantilever Sensors

Abstract:
Current scanning probe microscopes and micro/nano-mechanical displacement sensing techniques rely on free-space optical detection schemes. This results in complex and bulky solutions. In this project, we report the development of a suspended silicon waveguide cantilever resulting in an integrated approach that minimizes system complexity and allows high integration of a large number of sensors. The suspended silicon waveguide is optically coupled to a fixed waveguide. A shift in the position of the cantilever reduces the optical coupling. In this configuration, the device acts as a displacement sensor for applications in mass measurement through the resonant frequency shift; as well as a direct displacement sensor through the amplitude of the modulation in coupling.

Summary:
We developed a fabrication method for fiber-optic measurement of cantilever deflection and frequency response. The most important advantage of using optical fibers for cantilever characterization is their small size. The most common detection methods involve atomic force microscopy [1, 2], laser Doppler vibrometry [3] and interferometry [4], which require bulky and expensive equipment. In contrast to the elements that have been used until now for cantilever characterization, optical fibers allow the arrangement of compact and stable measuring systems. Moreover, the operational wavelength of the silicon waveguide covers the range used in telecommunication industry. Thus, the application of telecommunications components allows easy connection to the light source and detecting system, transferring data over a long distance as well as making the system inexpensive and easily available.

On the fabricated chip, the light coupled to the waveguide reaches its suspended section which acts as a cantilever. At the cantilever’s end, light propagates into free space. The light is partly reflected back to the cantilever and partly transmitted to the receiving waveguide. The amount of reflected/transmitted light depends strongly on the vertical deflection of the cantilever. Modulation intensity contains easily extractable information about the mechanical oscillations of the cantilever.

Samples were fabricated by electron beam lithography in the Leica VB6. A zero level alignment layer was patterned with PMMA and etched using SF6 and CF4 to define pit marks with approximately 500 nm depth. The waveguide level was patterned using FOX-12 (HSQ) as a resist layer over SOI wafers with device layer of 200 nm and buried layer of 3 µm of SiO2. Silicon waveguides were etched using ICP-RIE in the PT770 using Cl2 and BCl3 plasma, resulting in highly vertical and smooth waveguides. These samples were coated with a thin Si3N4 layer and a release aperture was patterned over the waveguides, aligned to the waveguide gap, and defined the length of the suspended cantilever. The Si3N4 was etched using the RIE in a CHF3:O2 plasma. A top cladding layer of SiO2 was deposited by PECVD and the sample was diced and polished. Finally, a coarse photolithography step was carried out to define a broad etch opening. Wet etching in Buffered HF was performed to remove the silicon oxide cladding around the cantilever section of the unprotected waveguide. Some samples were prepared without separation of the waveguides to allow further processing using the FEI FIB XP800 at the Motorola Nanofabrication Research Facility recently inaugurated at Florida International University.

Cantilevers with lengths varying from 2.5 to 50 µm were fabricated which yield resonance frequencies in the range of 500 KHz to 10 MHz. We are currently testing these devices in the Nanophotonics lab at FIU.

References:
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- Suspended silicon waveguide acts as cantilever sensor when coupled to a fixed receiving waveguide.
  - Direct displacement sensor for scanning probe and other applications.
  - Mass measurement sensor through the detection of resonant frequency shift of cantilever.

- Electron beam lithography with Leica VB6 used for waveguide and release area patterning as in Fig. 1. Fox-12 (HSQ) was resist mask and Cl₂/BCl₃ for ICP-RIE Si etch.

- Process is completed at the Motorola Nanofabrication Research Facility at Florida International University.
  - Cantilever is released by wet etching in buffered oxide etch through Si₃N₄ mask.
  - Florida International University’s FEI XP800 FIB was used to perform focused ion beam cutting of wave-guide without separation can eliminate “double resonance” caused by wet etch undercut.

Figure 1, top:
SEM of silicon cantilever and receiving optical waveguide. Rectangular release area is not covered by silicon nitride.

Figure 2, bottom:
The Focused Ion Beam FEI XP8000 at Florida International University was used to nanomachine the waveguide to improve the performance of the device.